PRIME

PROBE USING RADIOISOTOPES FOR ICY MOONS EXPLORATION

Jet Propulsion Laboratory
California Institute of Technology

Architecting Near-Term Ocean Worlds Subsurface Access Mission Concepts

Jean-Pierre Fleurial, Samuel Howell, Miles Smith, David Woerner, Emily Klonicki, Benjamin Hockman, Terry Hendricks, Yosi-Bar-Cohen, Adarsh Rajguru, Damon Landau, Jeremiah Gayle, and Brian Clement

Jet Propulsion Laboratory/California Institute of Technology

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STUDY TEAM

Jean-Pierre Fleurial
David Woerner
Terry Hendricks
Benjamin Hockman
Yoseph Bar-Cohen
Adarsh Rajguru
Emily Klonicki
Knut Oxnevad
Juergen Mueller
Marissa Cameron
Steve Vance
Jeremiah Gayle
Io Kleiser
Xiaoqi Bao
Margarita Brandt
Bailey Cassler
Michael Ullman

Samuel Howell
Miles Smith
Tom Nordheim
Scott Roberts
Cynthia Phillips
Scott Bryant
Benjamin Furst
Daniel Berisford
Hyeong Lee
Stewart Sherrit
Ian Fenty
Mircea Bradescu
Bill Nesmith
Richard Otis
Scott Perl
Mike Durka
Steve Johnson (INL)

Accelerator Phase:
Enrico Ossola
Eli Skulsky
Vilupanur Ravi
Marianne Gonzalez
Brian Clement
David Tuman
Damon Landau
Keith Billings
Will West
Rashied Amini
Richard Kidd
Steve Zusack

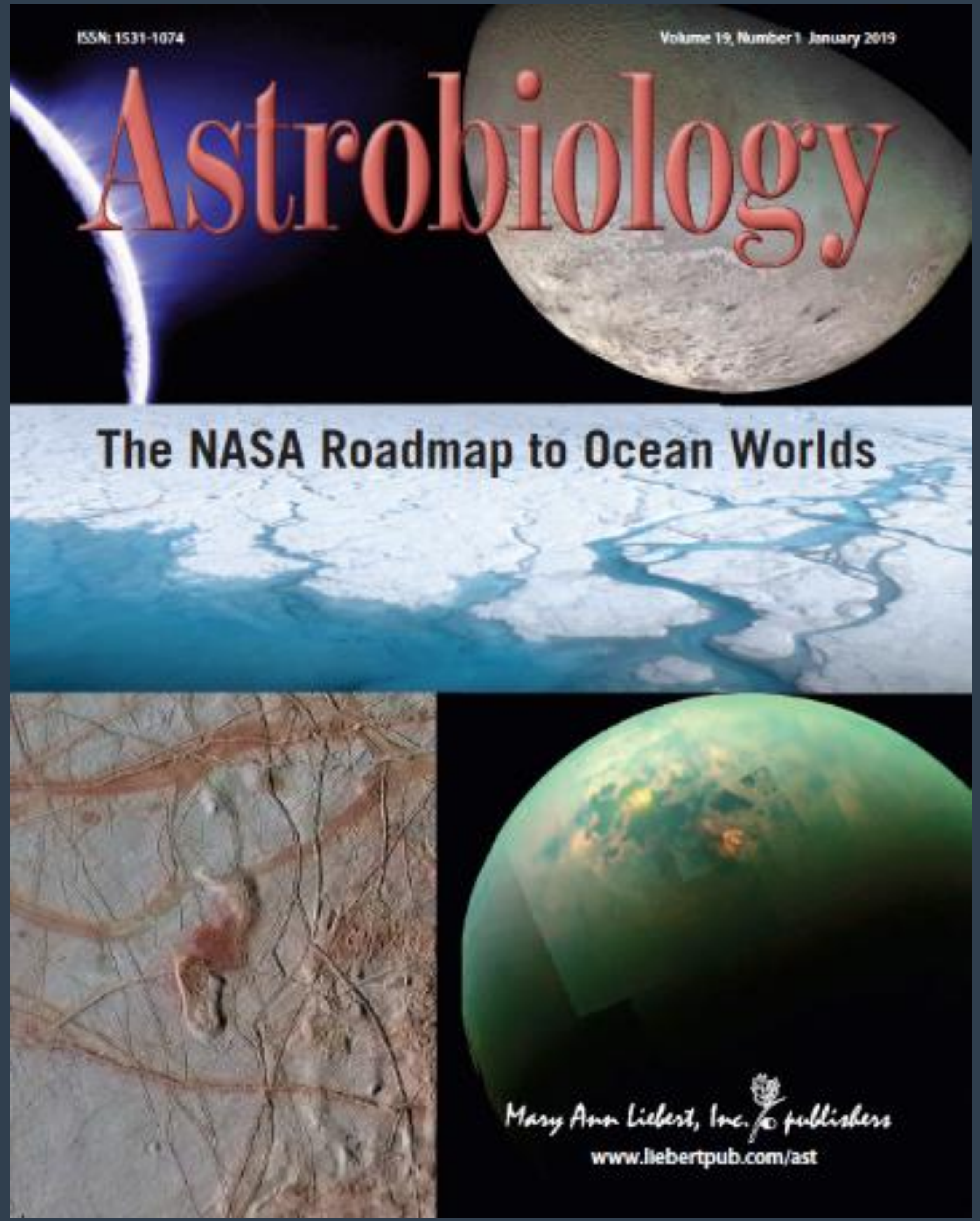
A special thanks to Faith Oftadeh, our communications mentor

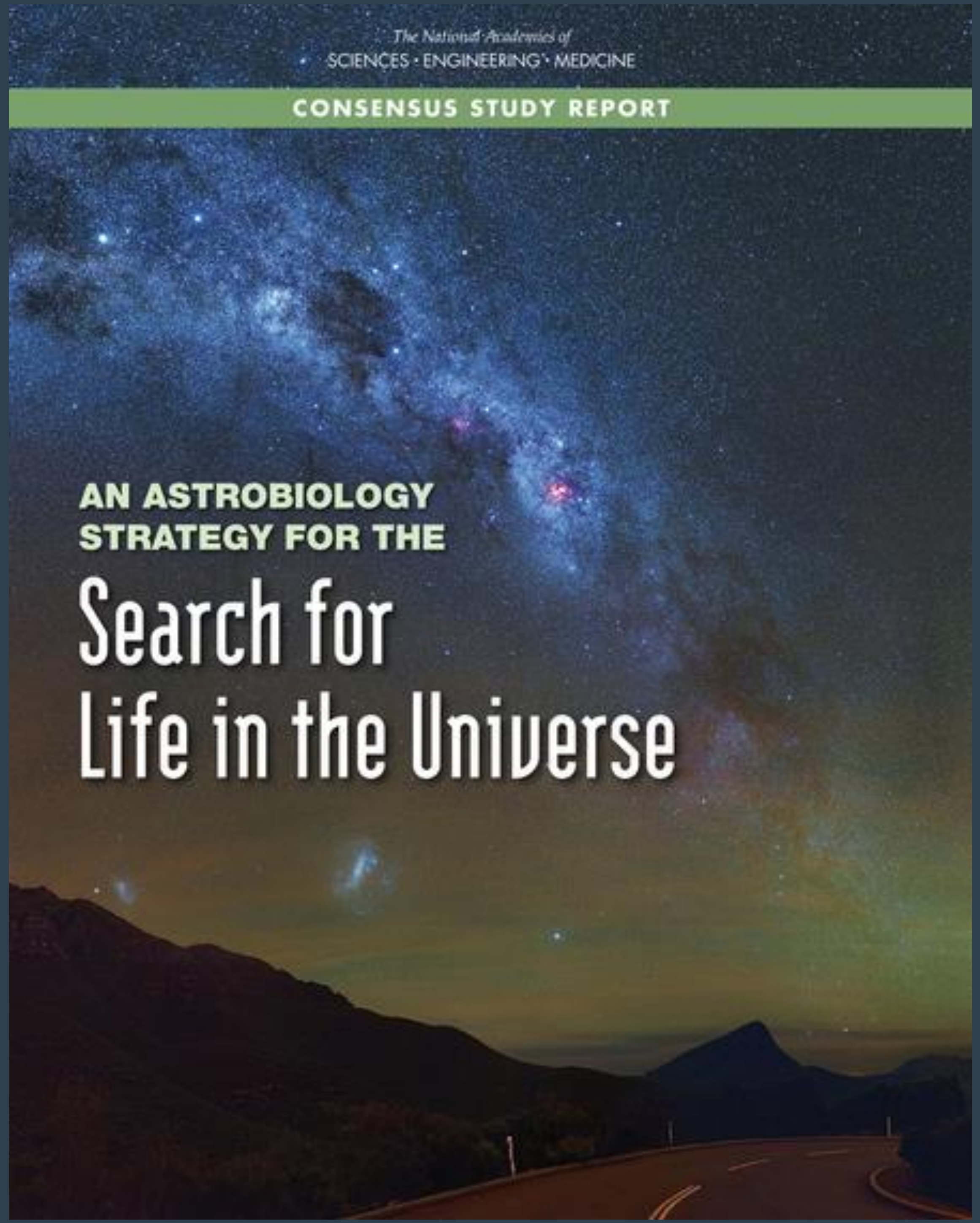
P R I M E

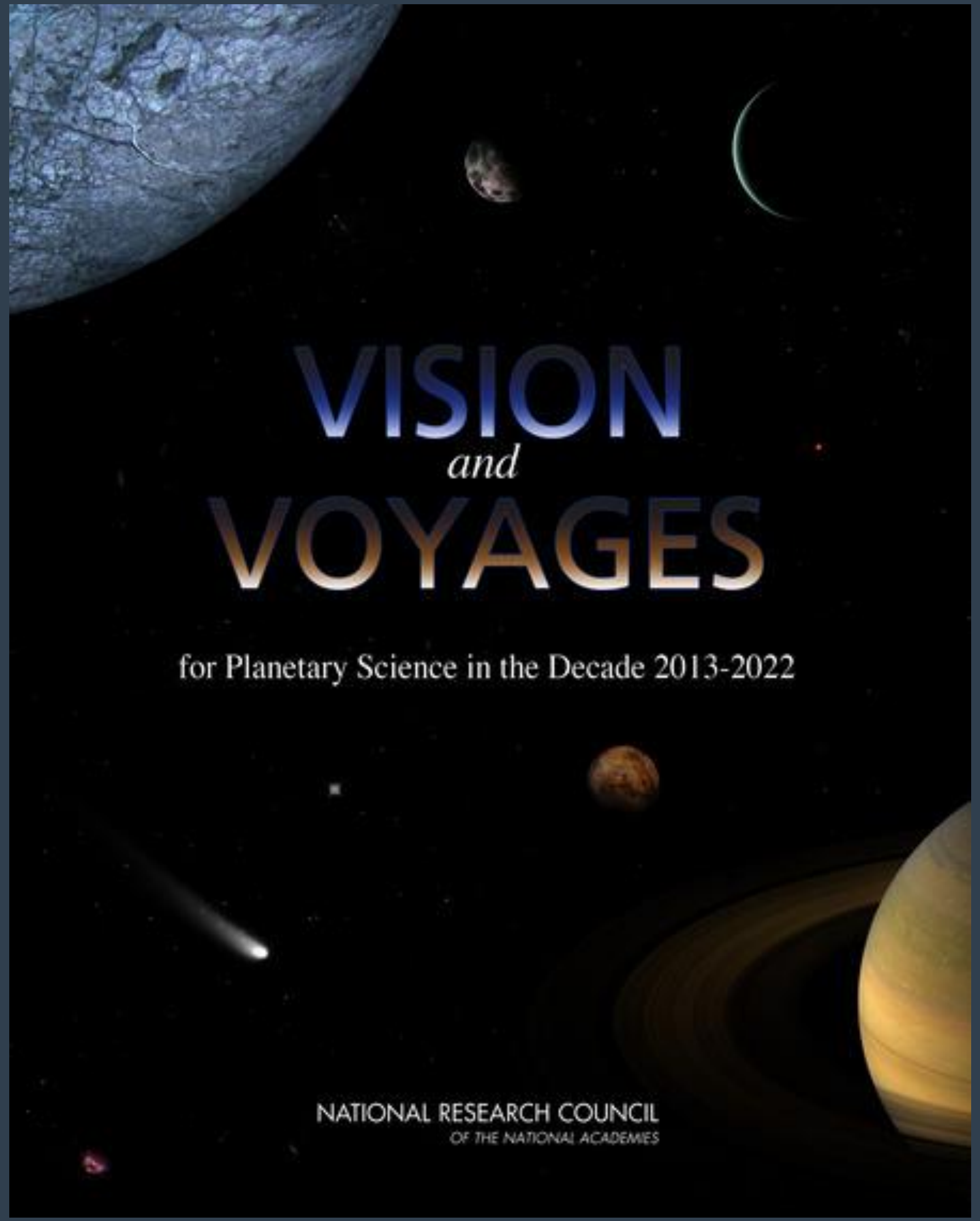
Introduction

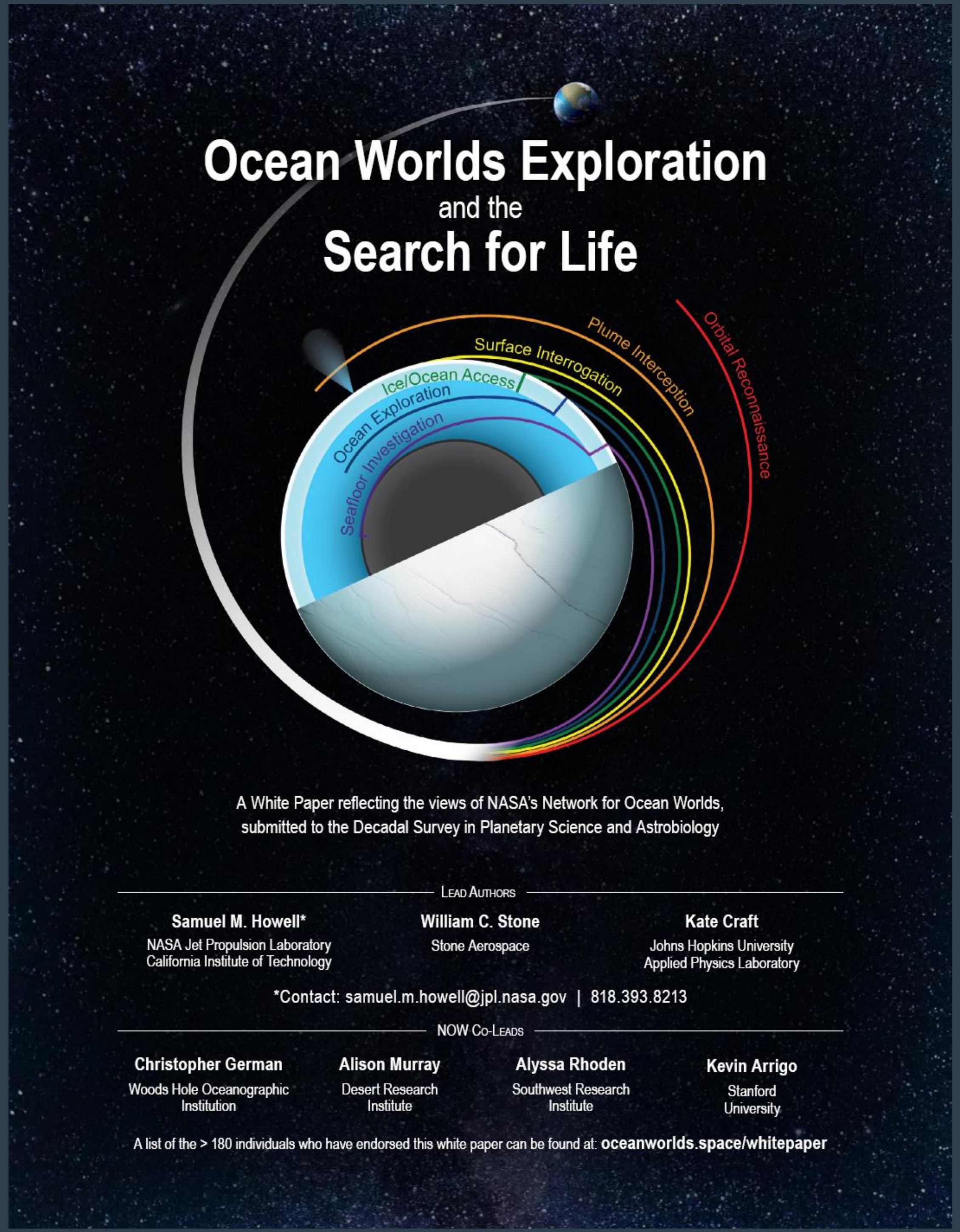
SCIENCE DRIVERS

Our driver: Science communities' recognition that the search for extant life is best answered through *in situ* exploration of the ice shell interior and ocean of Ocean Worlds, especially those of Europa and Enceladus







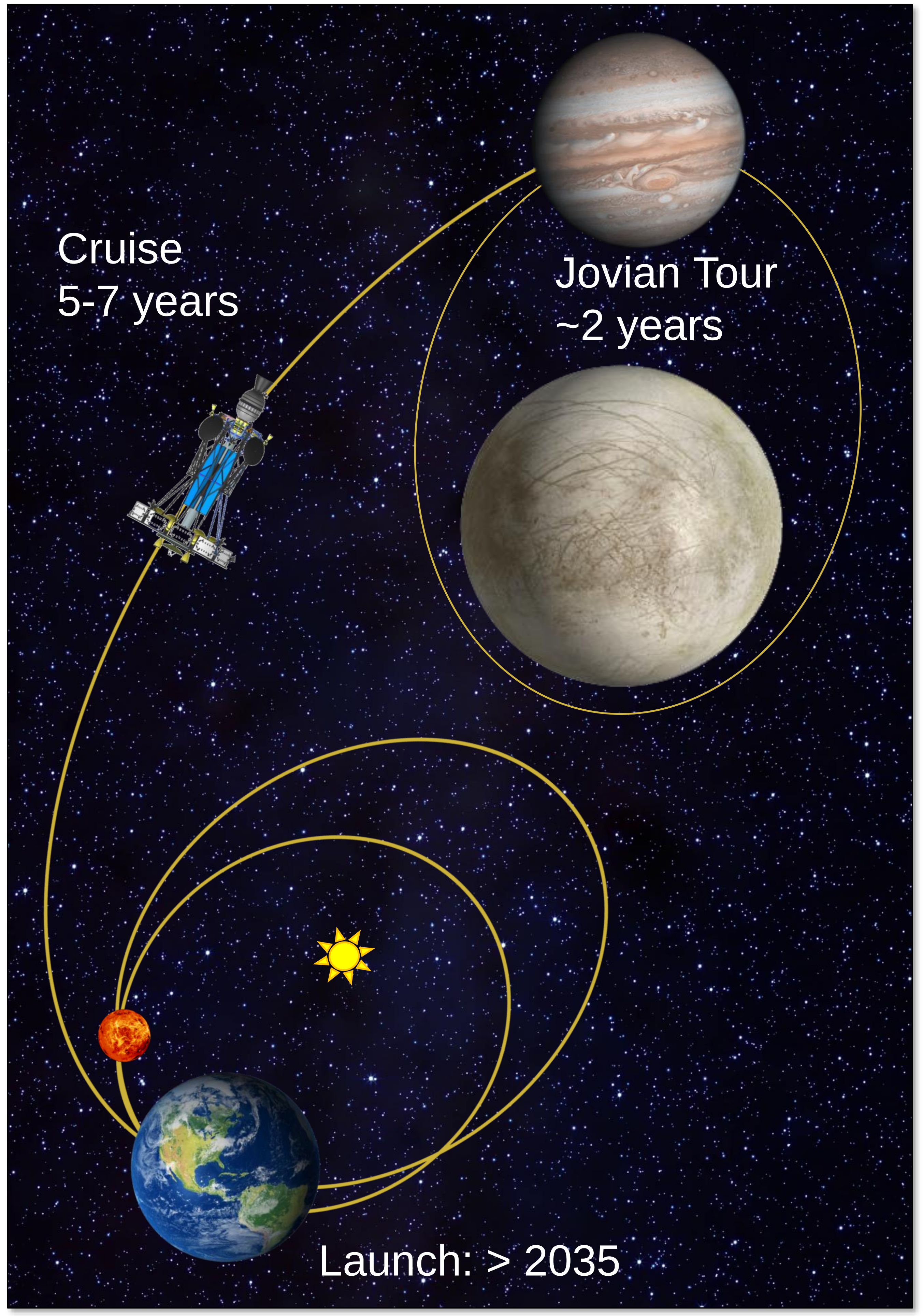


Our Goal: To descend beneath the ice of ocean worlds, characterize their subsurface, their habitability, and search for life

MISSION CONCEPT

A Notional Mission to Europa

Launch, Cruise, and Jovian Tour



Deorbit, Descent, & Landing (DDL)

Ice **E**ntry, **D**escent, & **O**cean Access (EDO)

OCEAN ACCESS REQUIRES SOME MISSING PIECES:

Operation through a new planetary subsurface mission phase:

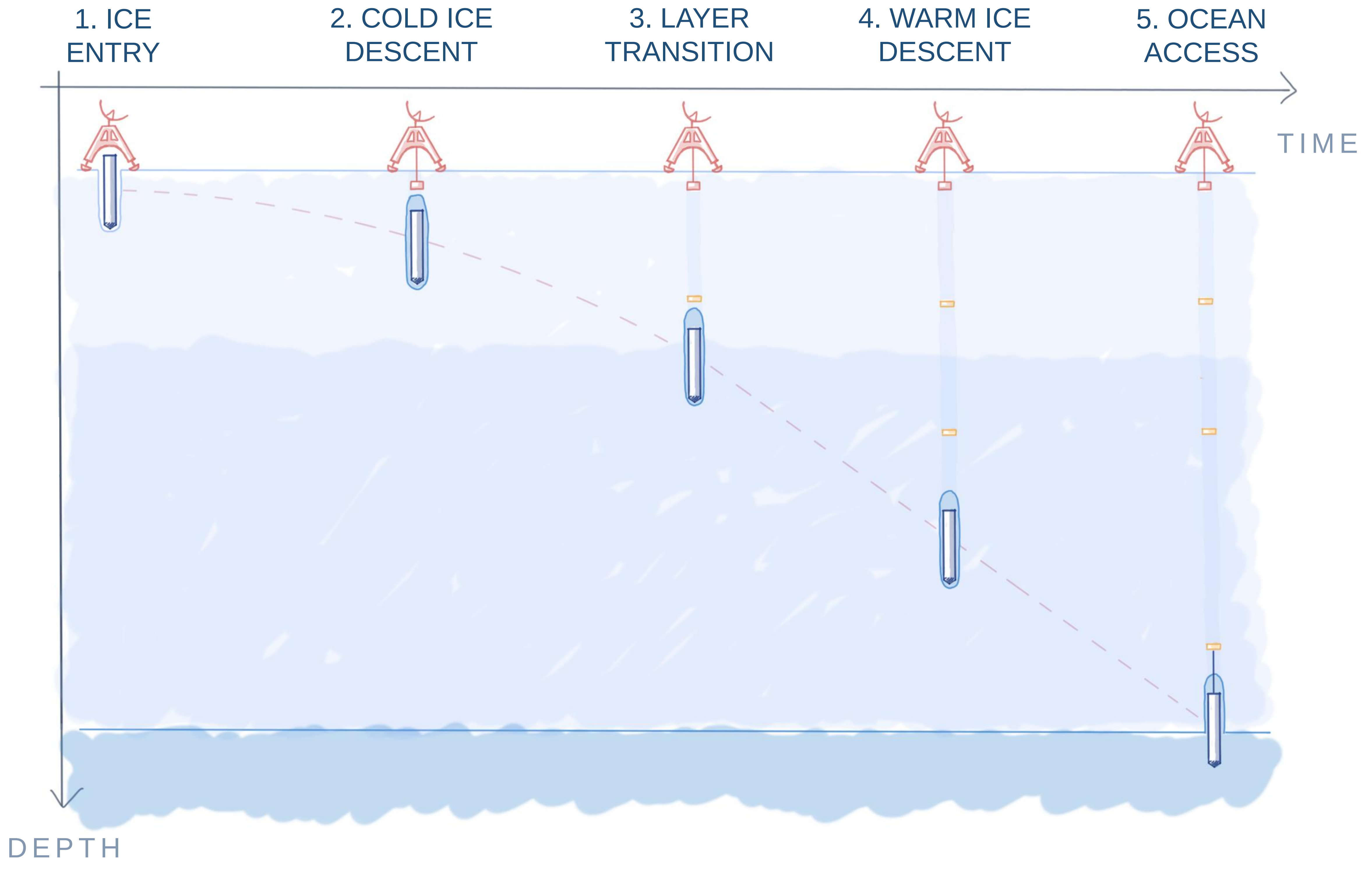
Ice Entry, Descent, and Ocean Access (EDO)

A new science-driven, autonomous mobility platform:

The Cryobot (PRIME)

THE EDO PHASE

THE MISSING PIECE OF AN OCEAN-ACCESS CONCEPT OF OPERATIONS



MISSION-ENABLING FEATURES

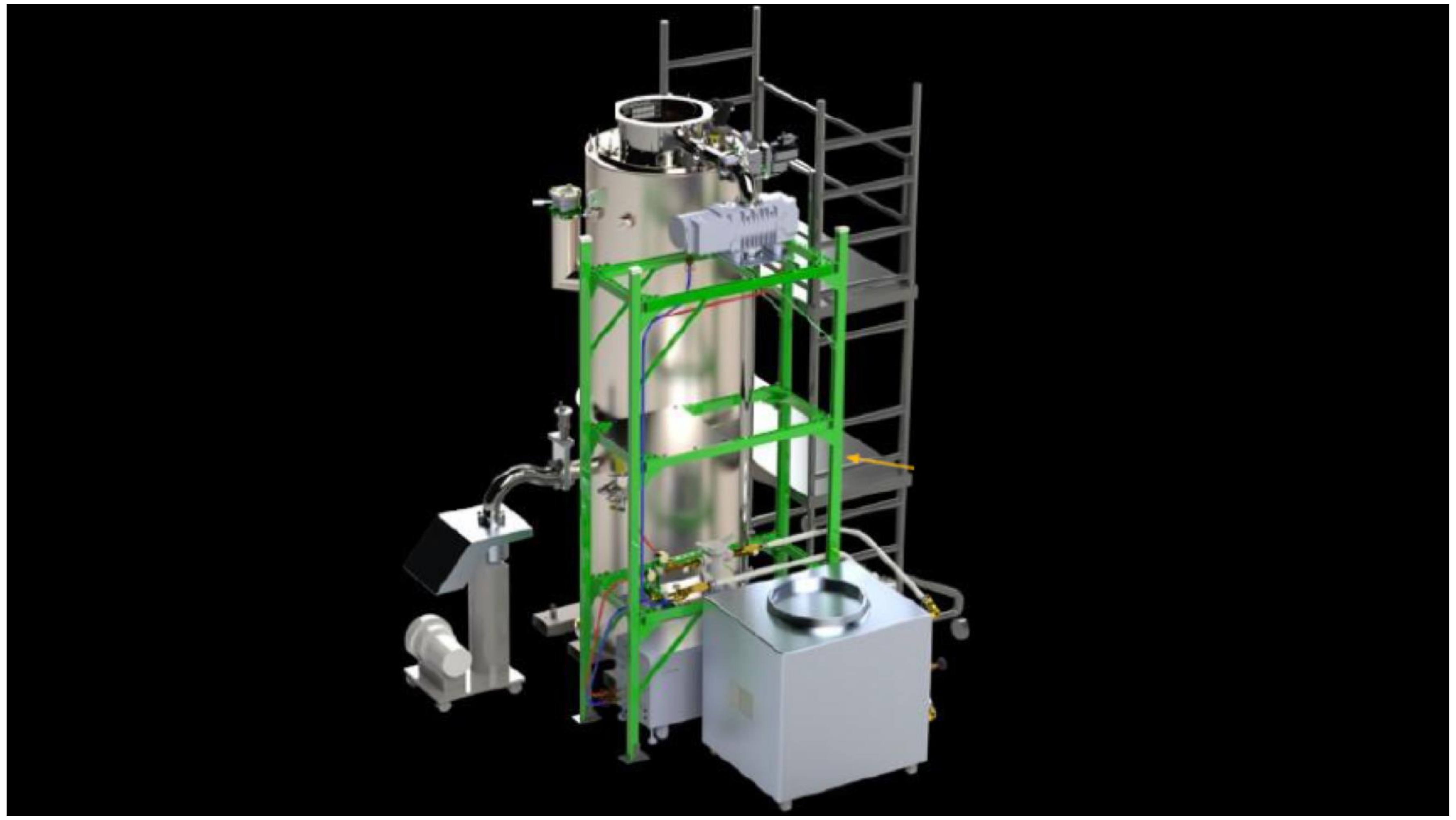
1. Entering the ice and disconnecting from the lander
2. Descending through cold, brittle ice, while detecting and mitigating hazards
3. Deploying communication relays as the environment changes
4. Sampling from the warm, convective layer
5. Anchoring at the ice-ocean interface to complete the science objectives

Completing the journey in a programmatically-acceptable time

THE EDO PHASE

THE MISSING PIECE OF AN OCEAN-ACCESS CONCEPT OF OPERATIONS

DEMONSTRABLE IN THE LAB



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Completing the journey in a programmatically acceptable time

THE EDO PHASE

THE MISSING PIECE OF AN OCEAN-ACCESS CONCEPT OF OPERATIONS

...AND IN THE FIELD

MISSION-ENABLING FEATURES

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Completing the journey in a programmatically-acceptable time

P R I M E

System Concept Overview

HALF-CENTURY OF PROGRESS

1962 Philberth demonstrates the first “hot penny” melt probe to 1 km

1967 Aamot publishes the first detailed description of an integrated melt probe for polar applications for the US Army

1990s Resurgence in planetary melt probe interest within NASA and JPL after discovery of Europa’s ocean by Galileo

1999 First radioisotope ocean access concepts proposed for planetary oceans

2001 ***Elements of flight system first demonstrated to 20 m in Svalbard***

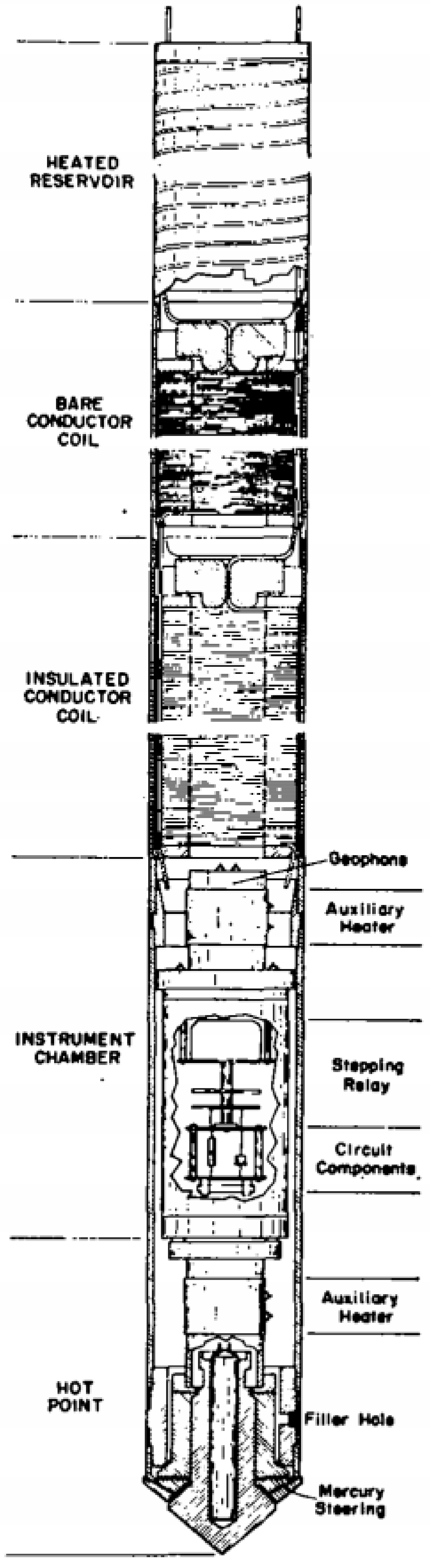
2000s Development continues through multiple programs, but several key technologies are underdeveloped; NASA abandons plans to access lake Vostok with a cryobot

2010s As technologies develop, NASA again begins making cryobot awards through ColdTech, PICASSO, MATISSE, PSTAR

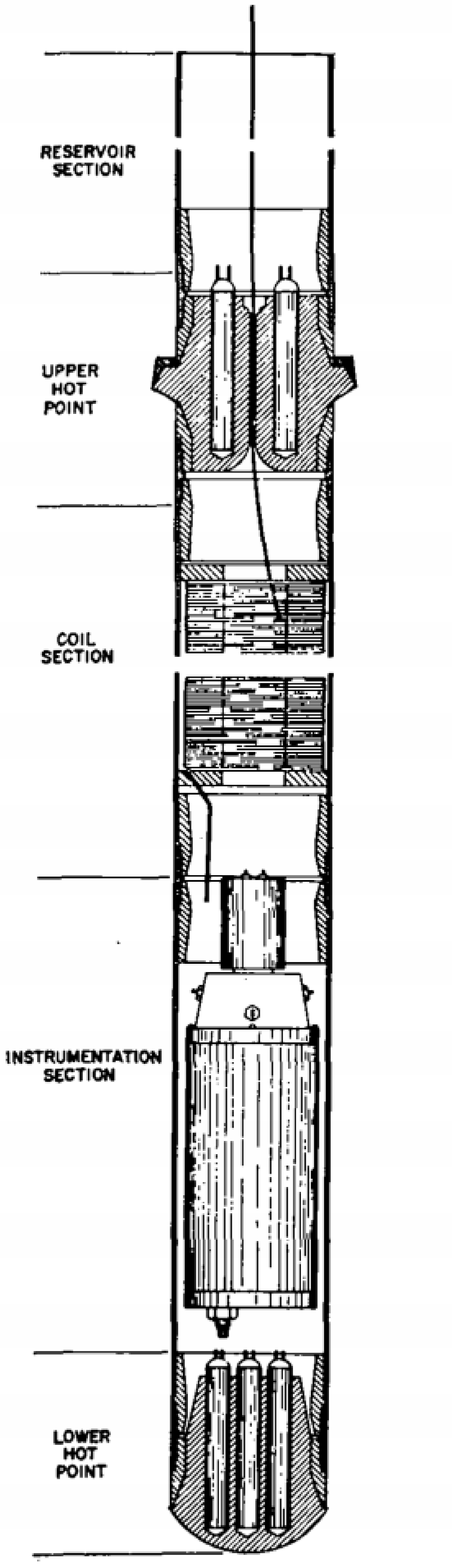
2017 NASA Convenes KISS study on accessing the subsurface oceans of icy worlds, determining that science and technology advances now allow planetary ocean access architectures to close for the first time

2018 Following study results, NASA invests $10M in cryobot subsystems research through the SESAME program

2019 Initiated in-depth study to advance an integrated, flight-like ocean access cryobot system concept to close remaining technology gaps



THE PHILBERTH PROBE

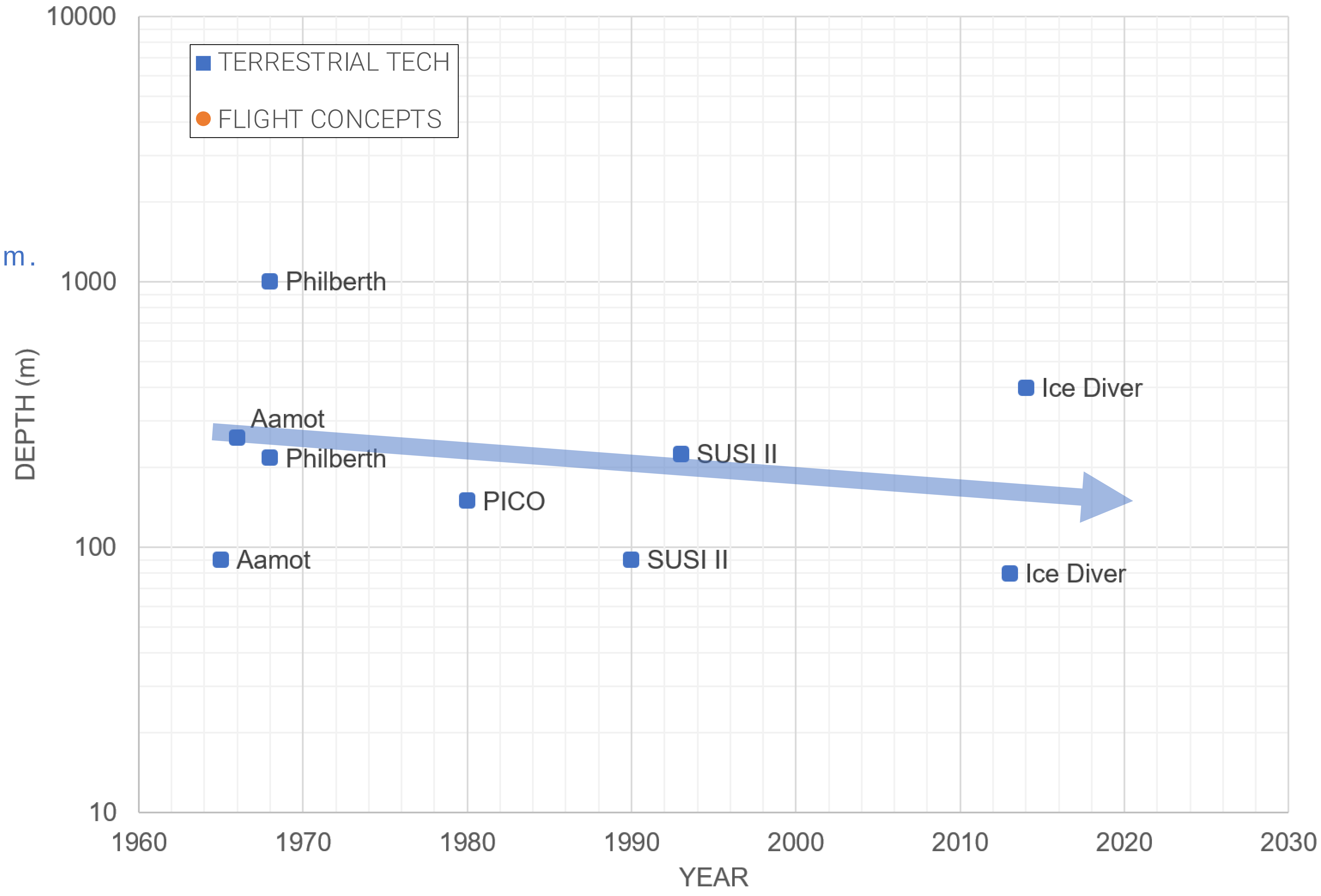


THE PENDULUM PROBE

PREVIOUS EFFORTS

TAKING CRYOBOTS TO NEW DEPTHS, ANCHORED IN FLIGHT REALISM

Deepest achieved with terrestrial tech is 1,005 m.



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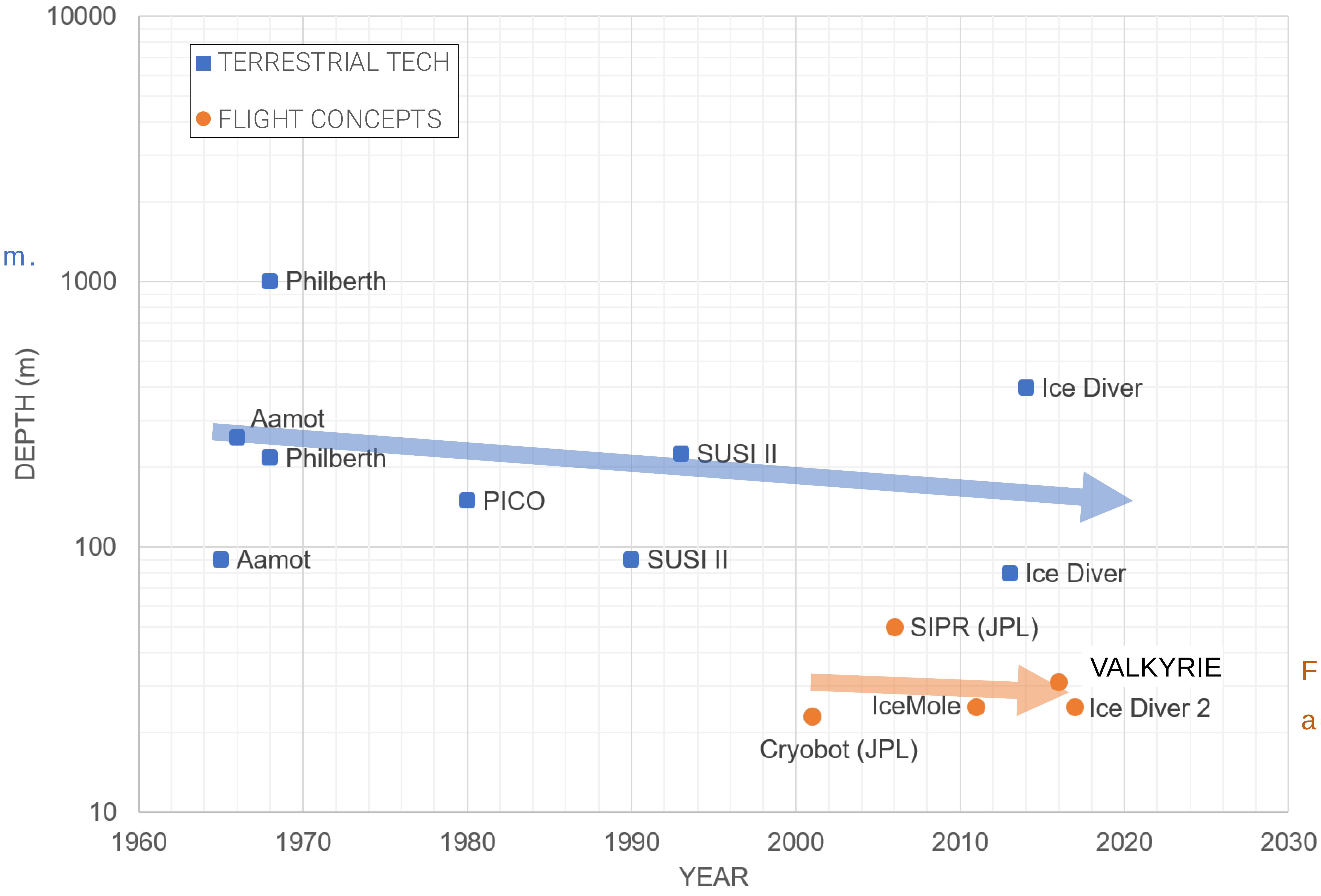

Flight-like systems have achieved only up to 50 m

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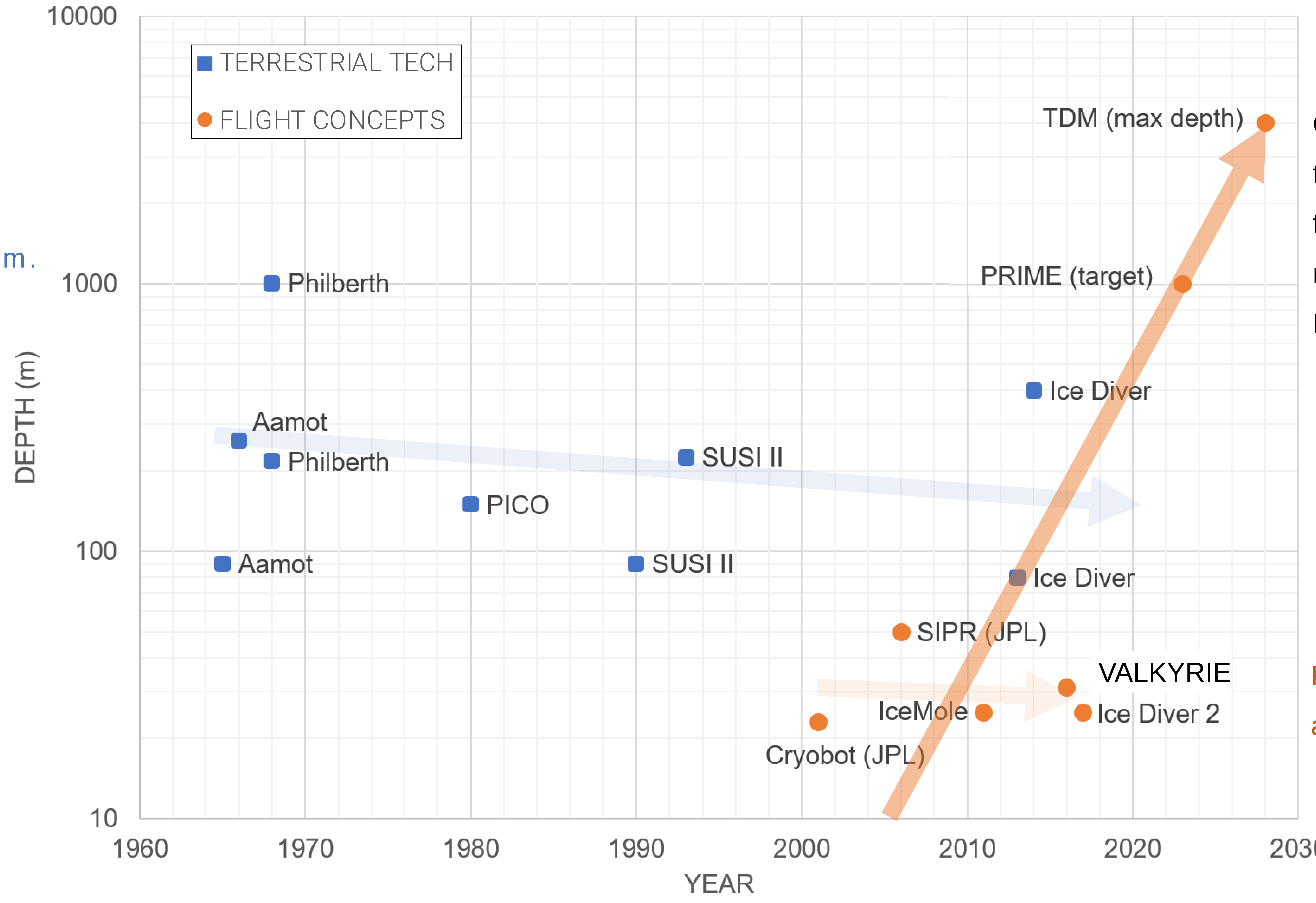


Objective is advancing technologies integrated into flight-like systems toward a near-term Technology Demonstration Mission

Flight-like systems have achieved only up to 50 m

MISSION-DERIVED CONSTRAINTS

THE OCEAN ACCESS "CHALLENGE BOX"

LAUNCH VEHICLES limits launched mass

Launched mass constrains LANDED MASS

LANDED MASS

Science community identified SCIENCE TARGETS

Of these, Europa environments impose most severe design case

Flight times to Europa are acceptable using available LAUNCH VEHICLES

SCIENCE TARGETS

OCEAN ACCESS CHALLENGE BOX

TIME TO OCEAN

LANDED MASS constrains Cryobot sizing

Cryobot sizing and available heat sources set system heat density

Cryobot heat density constrains TIME TO OCEAN

CRYOBOT SYSTEM CONCEPT

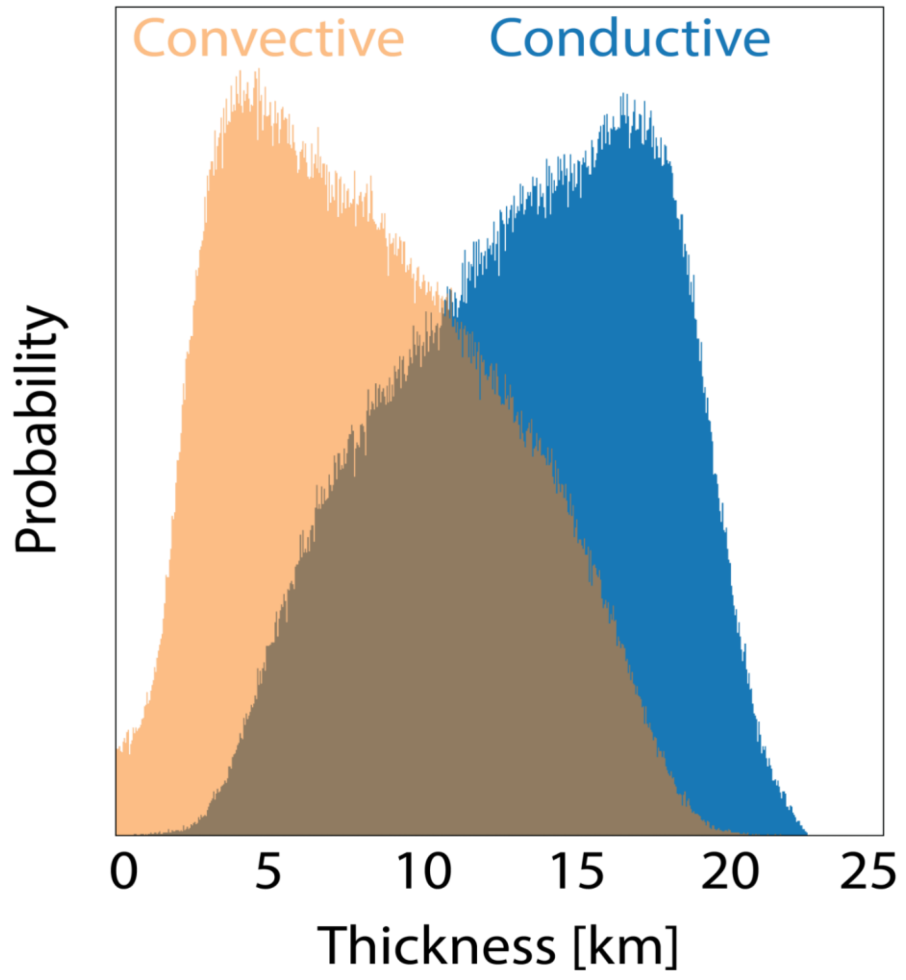
- ✓ Supports the SCIENCE TARGETS of Ocean Worlds
- ✓ Combined flight time and time to Oceans are acceptable
- ✓ LANDED MASS of < 350 kg fits on Europa-Lander-class lander
- ✓ Uses a radioisotope heat source and power system with clear path-to-flight
- ✓ TIME TO OCEAN is 2-6 years

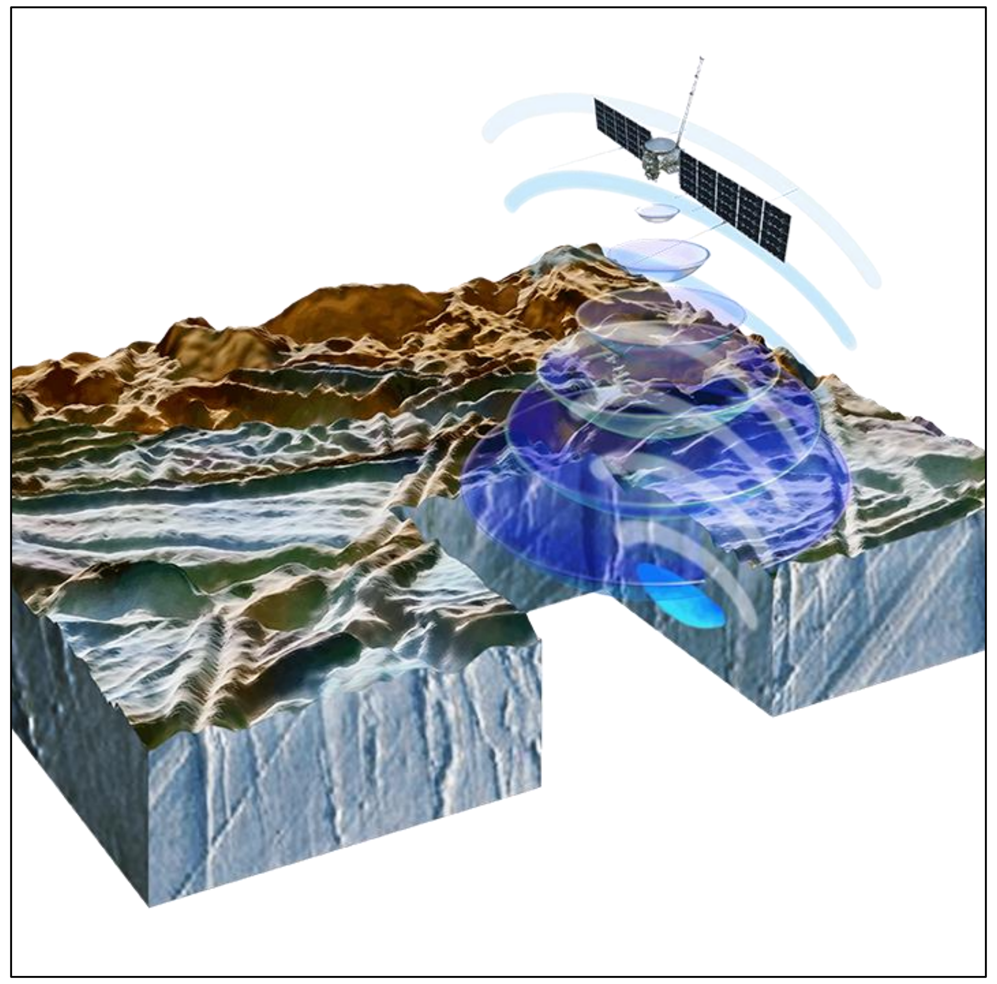
DESIGN DRIVEN BY ICE SHELL CONFIGURATION AND THICKNESS

DEFINING ENVIRONMENTS TO SUPPORT PROGRESS FORWARD

NEW ANALYSIS

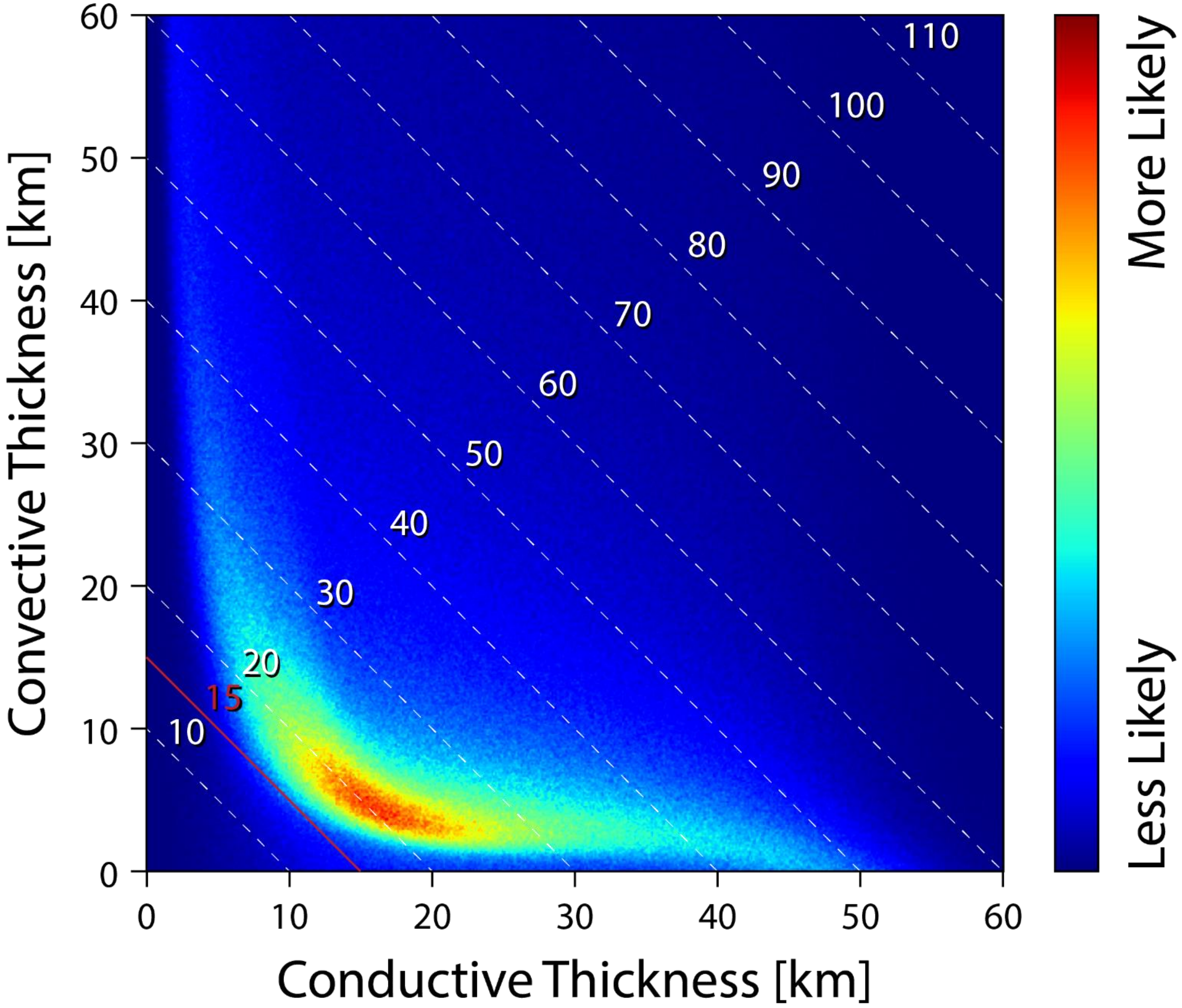
Manuscript outlining Monte Carlo simulation using full current state of knowledge to predict full ice shell and layer thickness





MAJOR RESULT

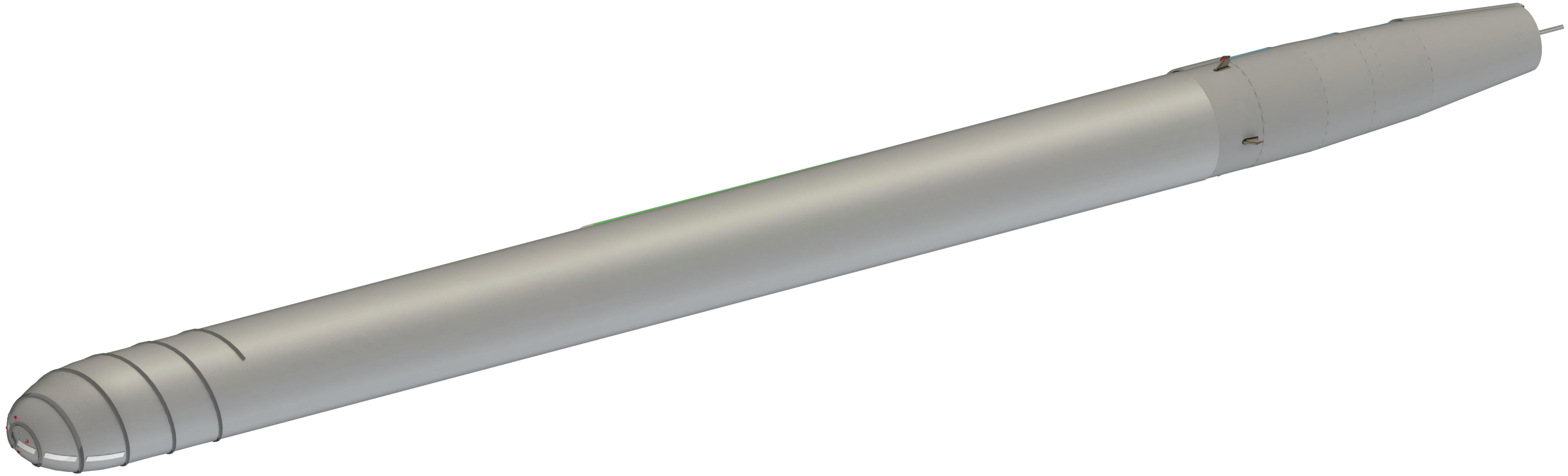
Presented to the Europa Clipper Interior Working Group and invited as one of two Keynote icy satellite talks at the 2020 Europlanet Science Congress (EPSC)



FLIGHT SYSTEM CONCEPT DEVELOPMENT

ARCHITECTURE DEVELOPMENT:

Design Drivers → Functional Decomposition → Subsystems & System Trades → Performance Anchoring → Concept Integration → Key Critical Technologies



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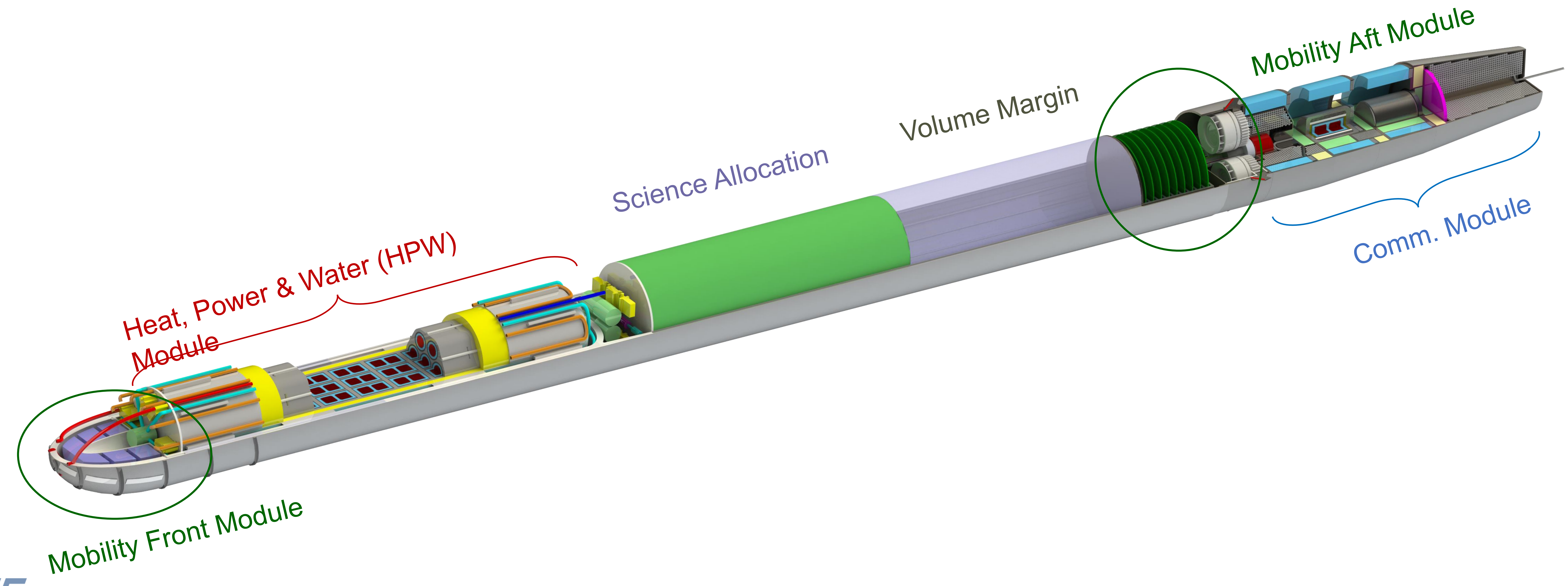

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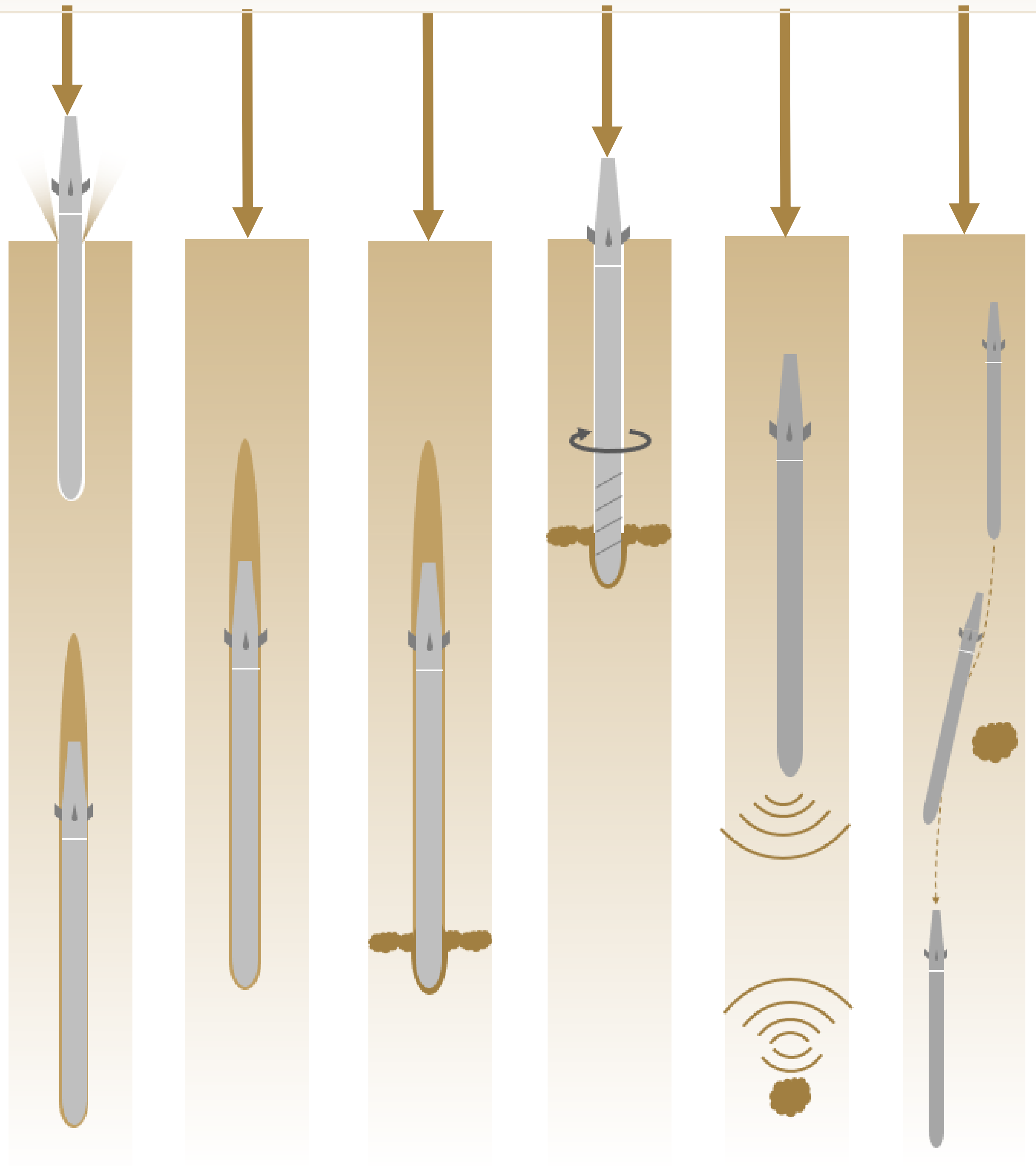
FUNCTIONAL DECOMPOSITION

THREE ENABLING TECHNOLOGIES

MOBILITY SYSTEM

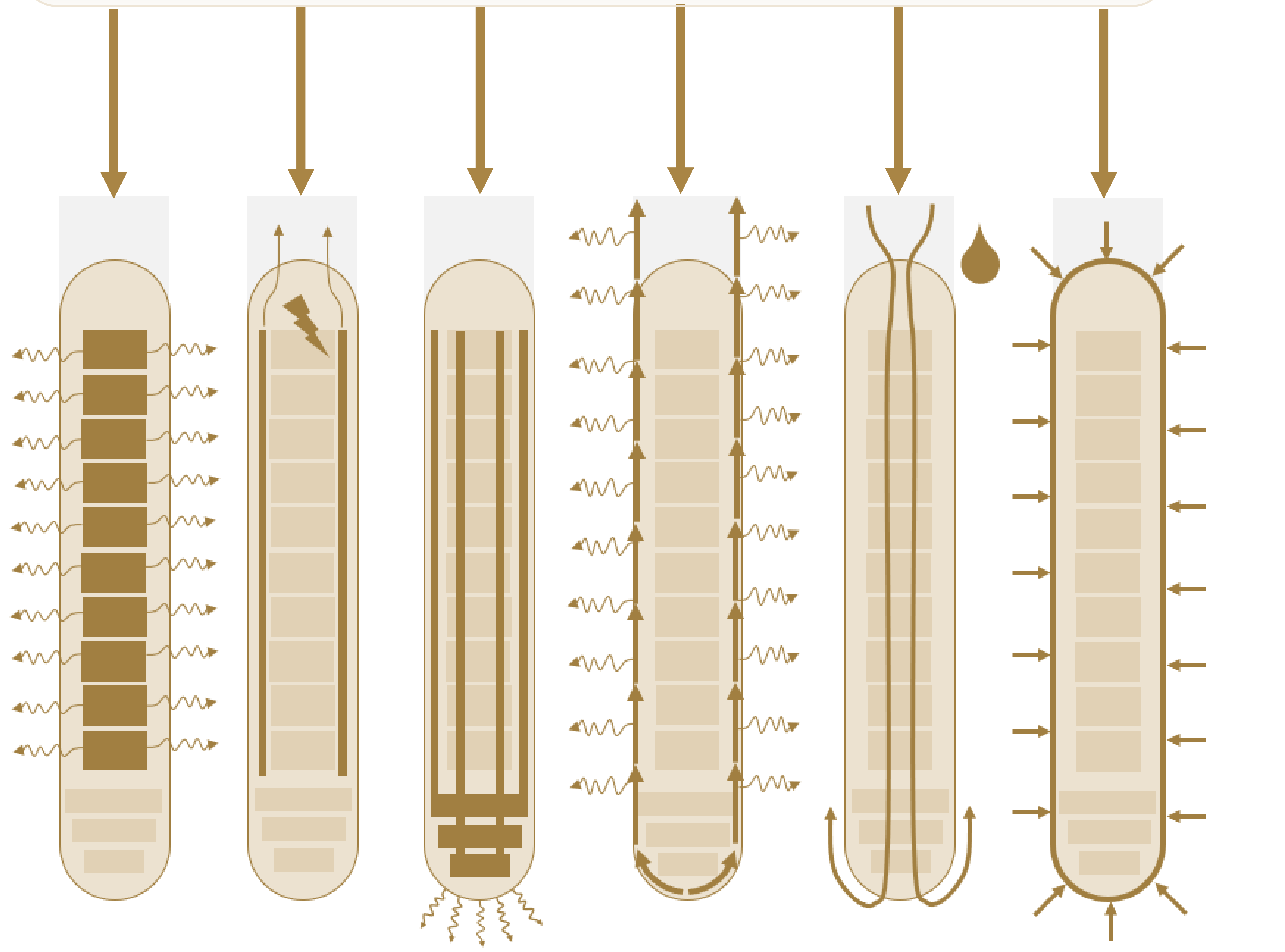
Safely and efficiently *descend* through the ice shell



6 essential Mobility functionalities

HEAT, POWER, WATER SYSTEM

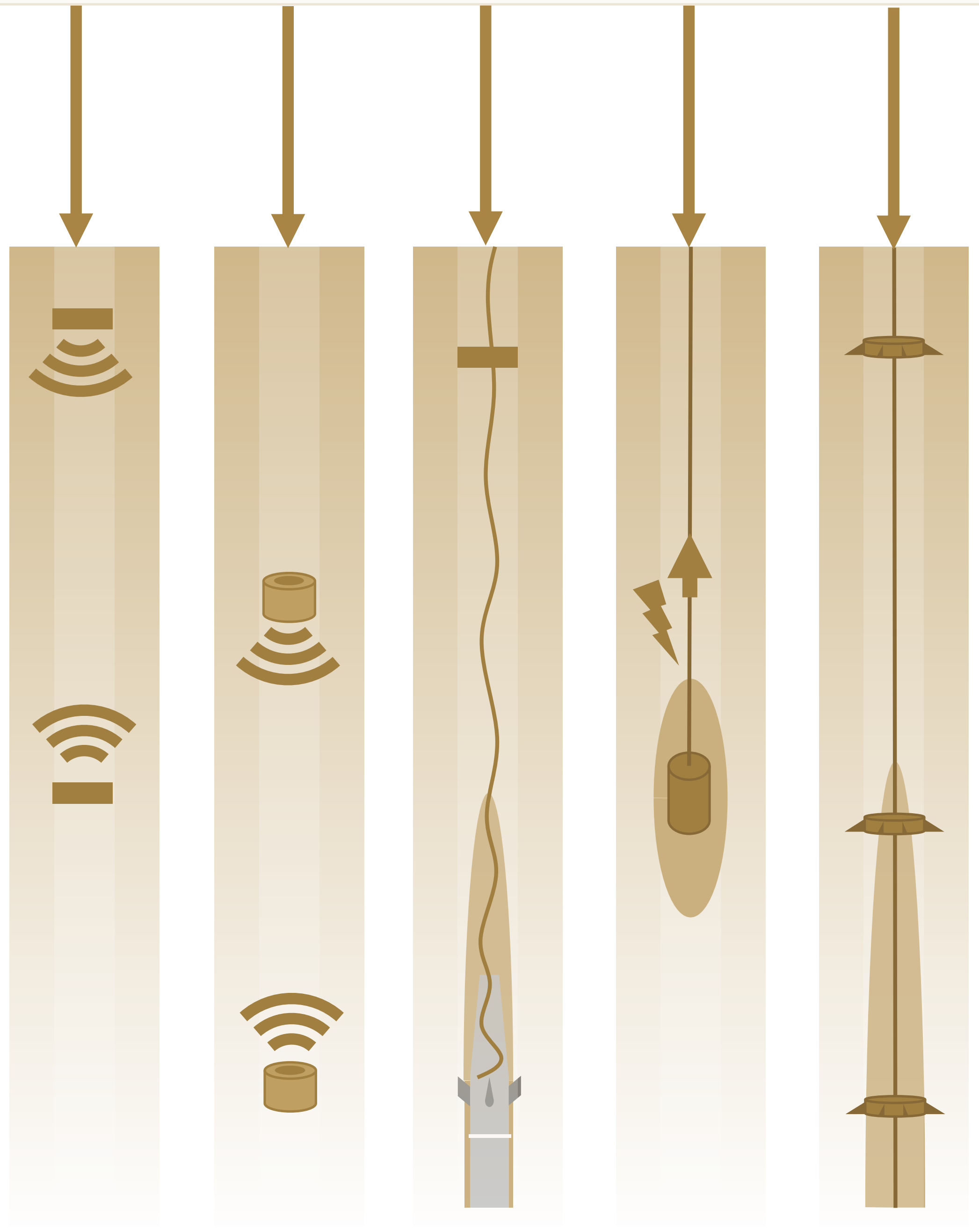
Effectively *distribute heat, electrical power, and fluid* through the interior of the Cryobot.



6 essential Heat, Power and Water functionalities

COMMUNICATION SYSTEM

Establish a *robust and redundant line of communication* through the ice shell.



5 essential Comm functionalities

Defined "Technology Modules" and their interdependencies that are critical to a successful completion of EDO

CRYOBOT SIZING

SIZING PROCESS

The *most driving* consideration for mission feasibility is the Cryobot's **size and in particular its diameter**.

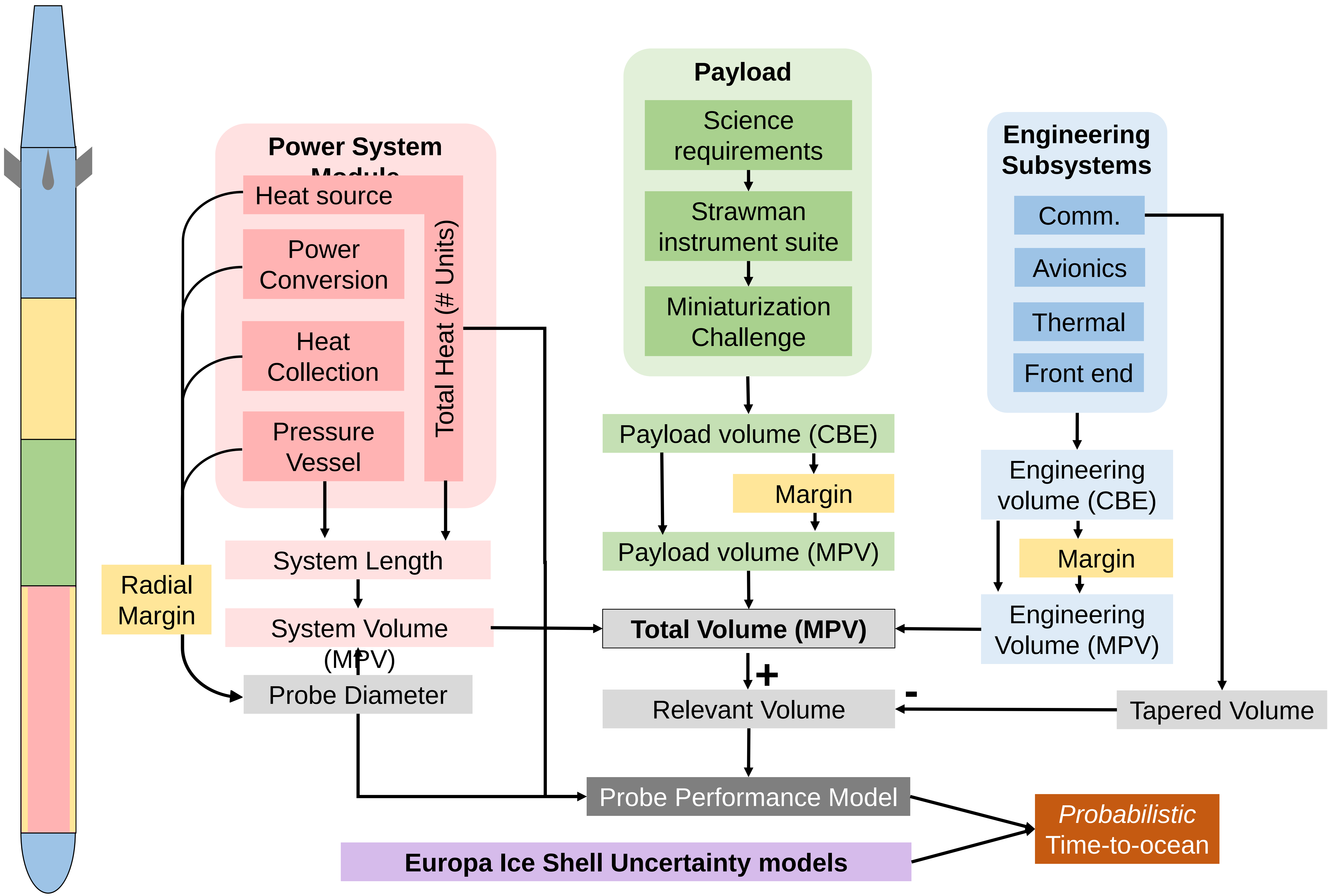
Sizing Process:

1. Define volume requirements for three primary components:
   - **Payload**
   - **Engineering Subsystems**
   - **Power System Module**

   Add appropriate volume **margin**

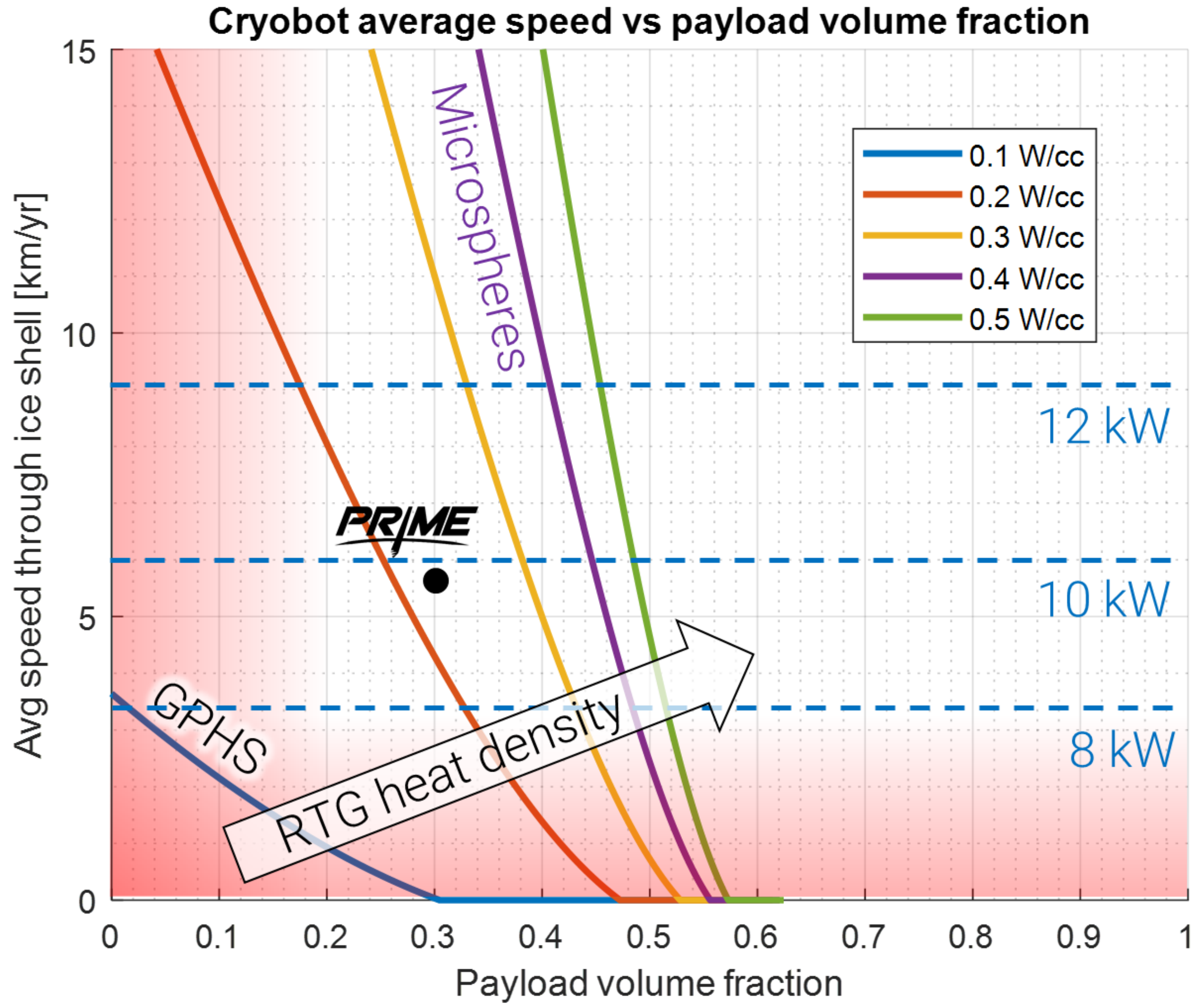
2. Size **heat source** to define **probe model.**

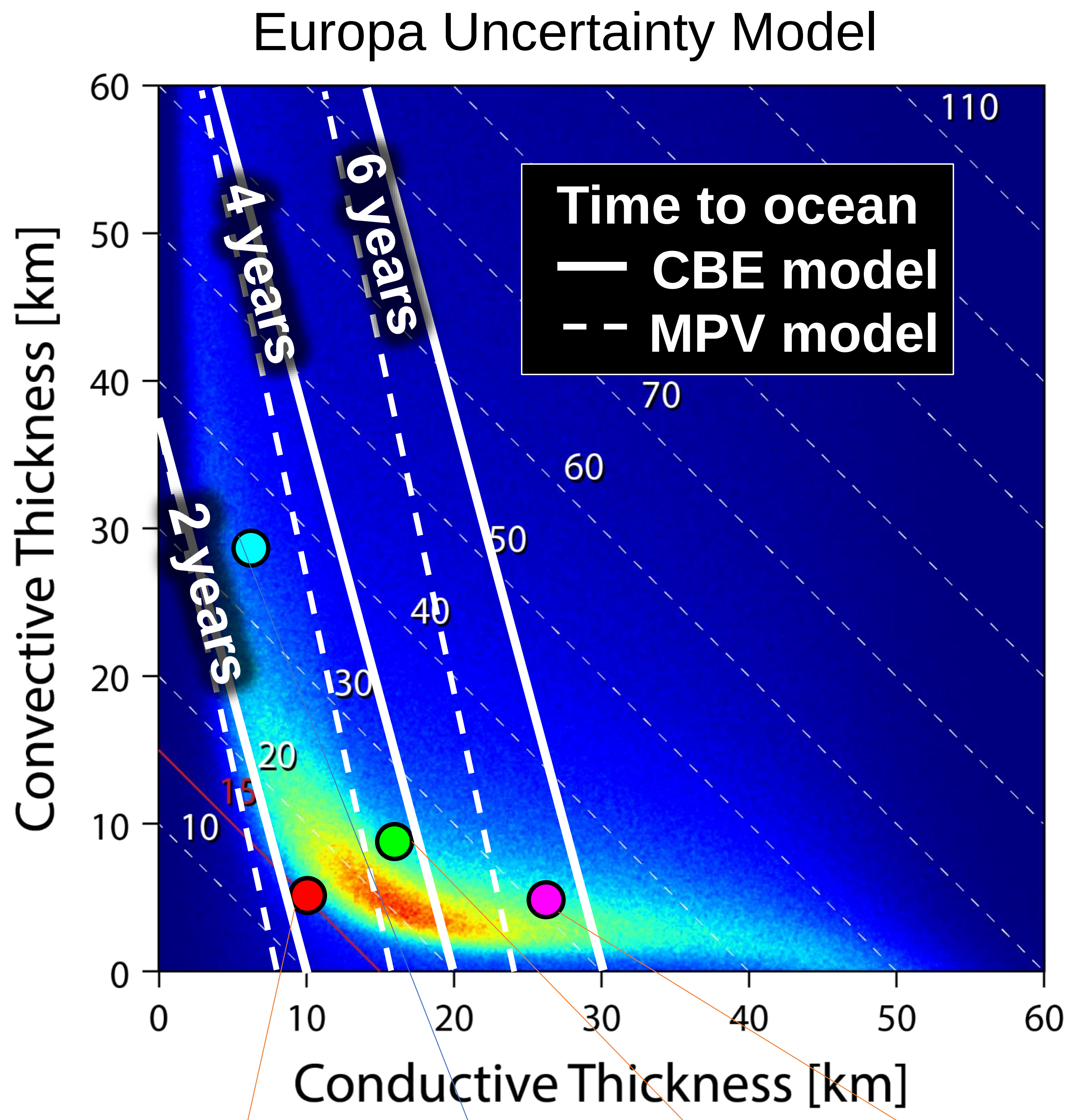
3. Use melt **performance models** to assess ***probe speed*** and **Time-to-ocean**

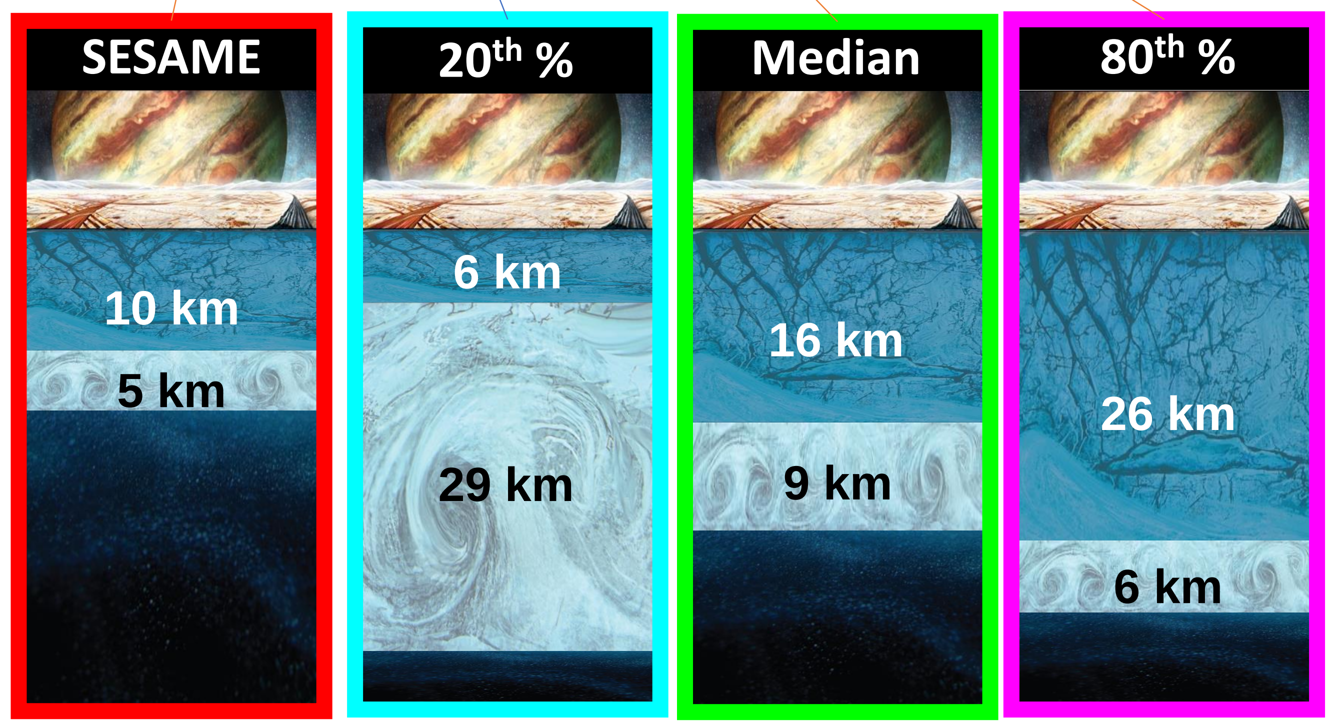


ARCHITECTURE CLOSURE

TIME TO OCEAN







Study results:

- 80% of realistic cases can be completed in < 6 years
- Ensures that EDO phase should not be longer than a typical cruise phase for an outer planets mission
- Ensures mission completion within the design life of the RTG

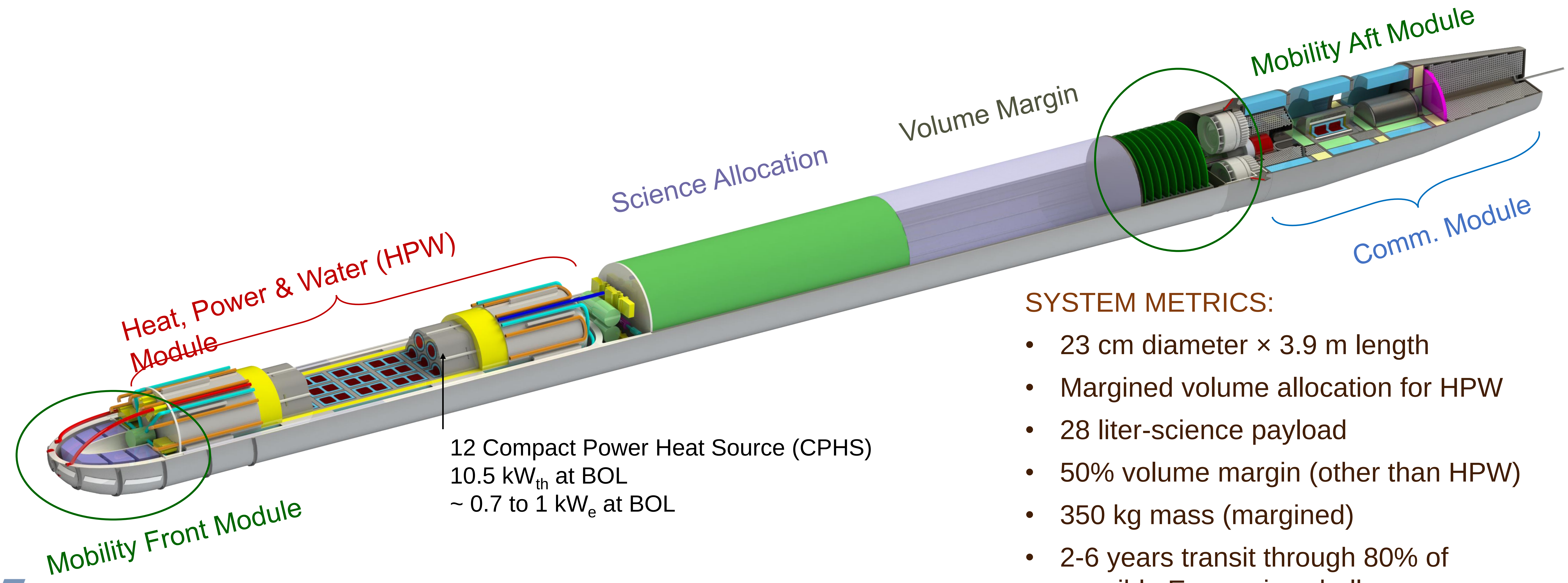
CBE: Current Best Estimate
MPV: Maximum Permitted Value

FLIGHT SYSTEM CONCEPT DEVELOPMENT

ARCHITECTURE DEVELOPMENT:

PROJECT PHASE

Design Drivers → Functional Decomposition → Subsystems & System Trades → Performance Anchoring → Concept Integration → Key Critical Technologies



SYSTEM METRICS:

- 23 cm diameter × 3.9 m length
- Margined volume allocation for HPW
- 28 liter-science payload
- 50% volume margin (other than HPW)
- 350 kg mass (margined)
- 2-6 years transit through 80% of possible Europa ice shells

P R I M E

Path Forward

EVOLUTION OF TECHNICAL SCOPE

FOCUSING ON MOST IMPACTFUL TECHNOLOGY DEVELOPMENTS

Focus on *holistic mission architecture*

- Establish mission feasibility
- Derived key trades and constraints

Focus on *Cryobot during EDO*

- System Architecture
- Functional Decomposition
- Technology gaps

Focus on *long-lead* technologies and their system *integration*

- Mobility System
- Heat, Power, and Water Module
- Communication System

Focusing on technologies and their interdependencies that are critical to successful completion of EDO

PRIME

Dare Mighty Things

Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration